

Cables, Connectors and Performance Testing

Chapter 5

5.0.0 CABLES, CONNECTORS AND PERFORMANCE TESTING

5.1.0 GENERAL COMMENTS

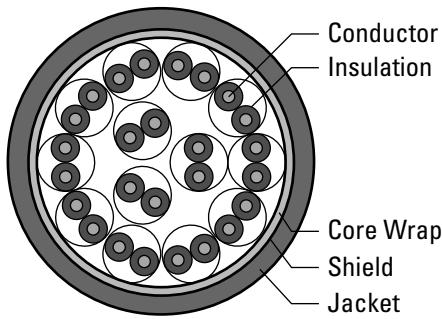
When choosing cables and connectors for LVDS it is important to remember:

1. Use controlled impedance media. The cables and connectors you use should have a differential impedance of about 100Ω . They should not introduce major impedance discontinuities that cause signal reflections.
2. Balanced cables (twisted pair) are usually better than unbalanced cables (ribbon cable, multi-conductor) for noise reduction and signal quality. Balanced cables tend to generate less EMI due to field canceling effects and also tend to pick up electromagnetic radiation as common-mode (not differential-mode) noise, which is rejected by the receiver.
3. For cable distances $< 0.5\text{m}$, most cables can be made to work effectively. For distances $0.5\text{m} < d < 10\text{m}$, CAT 3 (Category 3) twisted pair cable works well and is readily available and relatively inexpensive. Other types of cables may also be used as required by a specific application. This includes twin-ax cables built from separate pairs and ribbon style constructions, which are then coiled.

5.2.0 CABLING SUGGESTIONS

As described above, try to use balanced cables (twisted pair, twin-ax, or flex circuit with closely coupled differential traces). LVDS was intended to be used on a wide variety of media. The exact media is not specified in the LVDS Standard, as it is intended to be specified in the referencing standard that specifies the complete interface. This includes the media, data rate, length, connector, function, and pin assignments. In some applications that are very short ($< 0.3\text{m}$), ribbon cable or flex circuit may be acceptable. In box-to-box applications, a twisted pair or twin-ax cable would be a better option due to robustness, shielding and balance. Whatever cable you do choose, following the suggestions below will help you achieve optimal results.

5.2.1 Twisted Pair

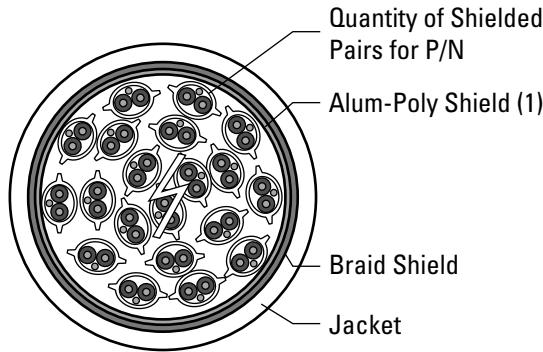


Drawing of Twisted Pair Cable, Cross-Section

Twisted pair cables provide a good, low cost solution with good balance, are flexible, and capable of medium to long runs depending upon the application skew budget. It is offered with an overall shield or with shields around each pair as well as an overall shield. Installing connectors is more difficult due to its construction.

- a) Twisted pair is a good choice for LVDS. Category 3 (CAT3) cable is good for runs up to about 10m, while CAT5 has been used for longer runs.
- b) For the lowest skew, group skew-dependent pairs together (in the same ring to minimize skew between pairs).
- c) Ground and/or terminate unused conductors (do not float).

5.2.2 Twin-ax Cables



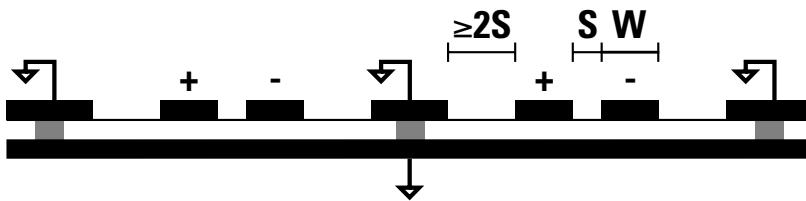
Drawing of Individually Shielded Parallel Pair Twin-ax Cable - Cross Section

Twin-ax cables are flexible, have low skew and shields around each pair for isolation. Since they are not twisted, they tend to have very low skew within a pair and between pairs. These cables are for long runs and have been commonly deployed in Channel Link and FPD-Link applications.

- a) Drain wires per pair may be connected together in the connector header to reduce pin count.
- b) Ground and/or terminate unused conductors.

5.2.3 Flex Circuit

Flex circuit is a good choice for very short runs, but it is difficult to shield. It can be used as an interconnect between boards within a system.

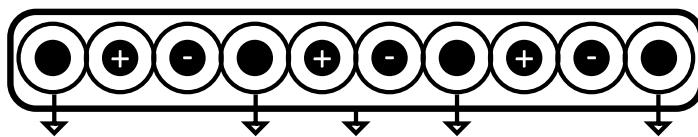


Flex Circuit - Cross-Section

- a) Closely couple the members of differential pairs ($S < W$). Do not run signal pairs near the edges of the cable, as these are not balanced.
- b) Use a ground plane to establish the impedance.
- c) Use ground shield traces between the pairs if there is room. Connect these ground traces to the ground plane through vias at frequent intervals.

5.2.4 Ribbon Cable

Ribbon cable is cheap and is easy to use and shield. Ribbon cable is not well suited for high-speed differential signaling (good coupling is difficult to achieve), but it is OK for very short runs.



Flat Cable - Cross-Section

- a) If ribbon cable must be used, separate the pairs with ground wires. Do not run signal pairs at the edges of the ribbon cable.
- b) Use shielded cable if possible, shielded flat cable is available.

5.2.5 Additional Cable Information

Additional information on cable construction may be found in National Application Note AN-916. Also, many cable, connector and interconnect system companies provide detailed information on their respective websites about different cable options. A non-inclusive list of a few different options is provided below:

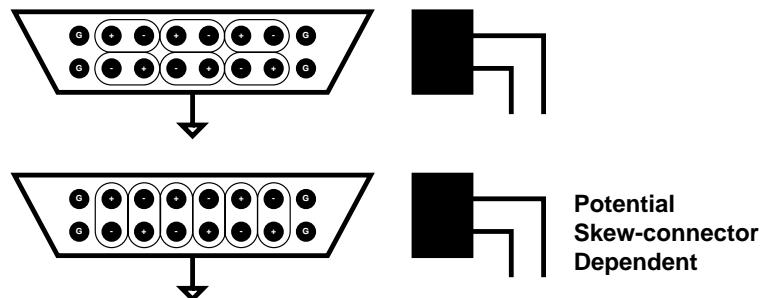
3M www.3M.com/interconnects/

Spectra-Strip Cable Products www.spectra-strip.amphenol.com/default.CFM

AMP <http://connect.amp.com/>

5.2.6 Connectors

Connectors are also application dependent and depend upon the cable system being used, the number of pins, the need for shielding and other mechanical footprint concerns. Standard connectors have been used at low to medium data rates, and optimized low skew connectors have been developed for medium to high-speed applications.



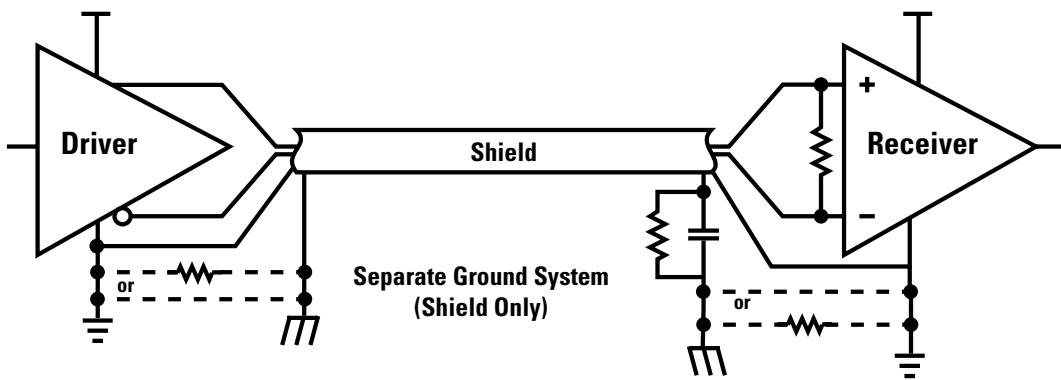
Typical Connector Pinouts

- a) Choose low skew, impedance matching connectors if possible.
- b) Group members of each pair together. Pins of a pair should be close together (adjacent) not separated from each other. This is done to maintain balance, and to help ensure that external noise, if picked up, will be common-mode and not differential in nature.
- c) Some connectors have different length leads for different pins. Group pairs on same length leads. Consult the connector manufacturer for the orientation of pins that yield the lowest skew and crosstalk for your particular connector. Shorter pin lengths tend to be better than long ones, minimize this distance if possible.
- d) Place ground pins between pairs where possible and convenient. Especially use ground pins to separate TTL/CMOS signals for LVDS signals.
- e) Ground end pins. Do not use end pins for high-speed signals, if possible, as they offer less balance.
- f) Ground and/or terminate unused pins.

Many different connector options exist. One such cable-connector system that has been used for LVDS with great results is the 3M "High-speed MDR Digital Data Transmission System." This cable system is featured on the National Channel-Link (48-bit) and LDI Evaluation Kits. The connector is offered in a surface mount option that has very small skew between all the pins. Different cable types are also supported.

5.3.0 CABLE GROUND AND SHIELD CONNECTIONS

In many systems, cable shielding is required for EMC compliance. Although LVDS provides benefits of low EMI when used properly, shielding is still usually a good idea especially for box-to-box applications. Together, cable shielding and ground return wires help reduce EMI. The shielding contains the EMI and the ground return wire (the pair shield or drain wire in some cables) and provides a small loop area return path for common-mode currents. Typically one or more pairs are assigned to ground (circuit common). Using one or more pair reduces the DCR (DC Resistance) of the path by the parallel connection of the conductors. This provides a known, very low impedance return path for common-mode currents.



Typical Grounding Scheme

In most applications the grounding system will be common to both the receiver and the driver. The cable shield is connected at one end with a DC connection to the common ground (frame ground). Avoid "pig-tail" (high inductance) ground wiring from the cable. The other end of the shield is typically connected with a capacitor or network of a capacitor and a resistor as shown in the above example. This prevents DC current flow in the shield. In the case where connectors are involved that penetrate the system's enclosure, the cable shield must have a circumferential contact to the connector's conductive backshell to provide an effective shield and must make good contact.

Note: It is beyond the scope of this book to effectively deal with cabling and grounding systems in detail. Please consult other texts on this subject and be sure to follow applicable safety and legal requirements for cabling, shielding and grounding.

5.4.0 LVDS SIGNAL QUALITY

Signal quality may be measured by a variety of means. Common methods are:

- Measuring rise time at the load
- Measuring Jitter in an Eye Pattern
- Bit Error Rate Testing
- Other means

Eye Patterns and Bit Error Rate Testing (BERT) are commonly used to determine signal quality. These two methods are described next.

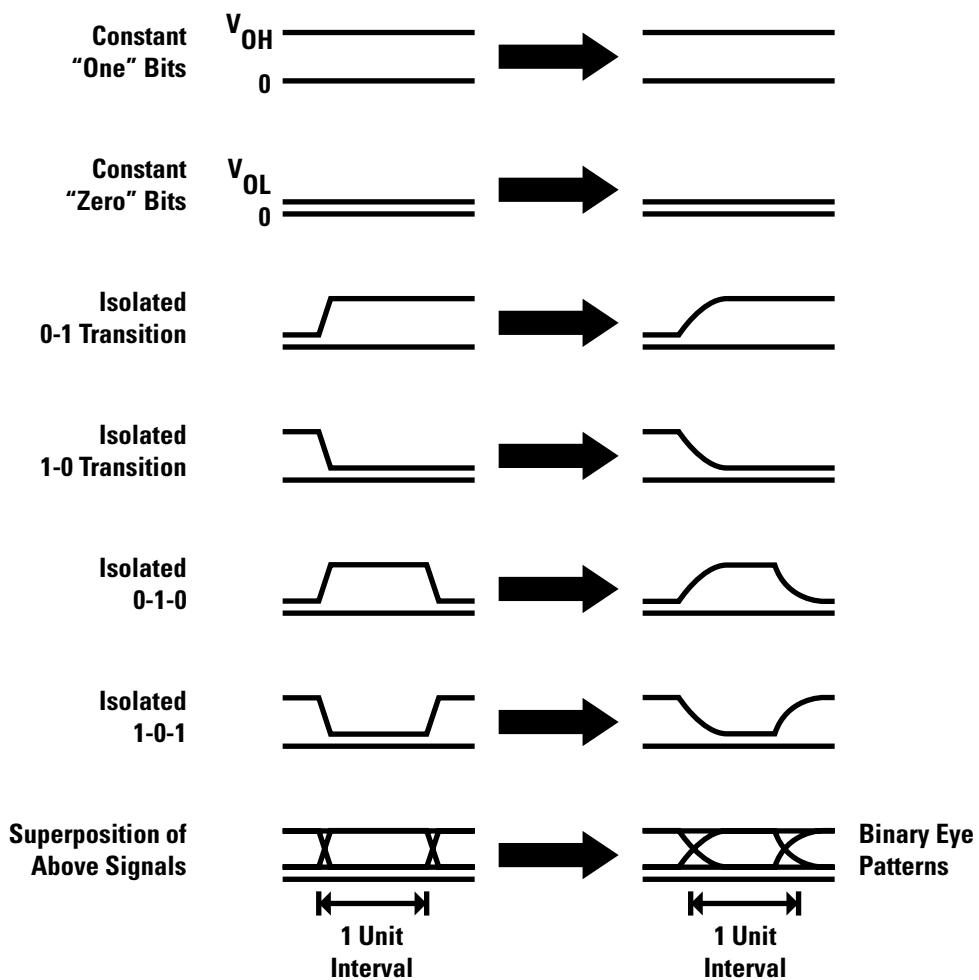
5.4.1 LVDS Signal Quality: Jitter Measurements Using Eye Patterns

This report provides an example of a data rate versus cable length curve for LVDS drivers and receivers in a typical application for a particular twisted pair cable. The questions of: "How Far?" and "How Fast?" seem simple to answer at first, but after detailed study, their answers become quite complex. This is not a simple device parameter specification. But rather, a system level question where a number of other parameters besides the switching characteristics of the drivers and receivers must be known. This includes the measurement criteria for signal quality that has been selected, and also the pulse coding that will be used (NRZ for example). Additionally, other system level components should be known too. This includes details about cables, connectors, and the printed circuit boards (PCB). Since the purpose is to measure signal quality, it should be done in a test fixture that closely matches the end environment — or even better — in the actual application. Eye pattern measurements are useful in measuring the amount of jitter versus the unit internal to establish the data rate versus cable length curves and therefore are a very accurate way to measure the expected signal quality in the end application.

5.4.2 Why Eye Patterns?

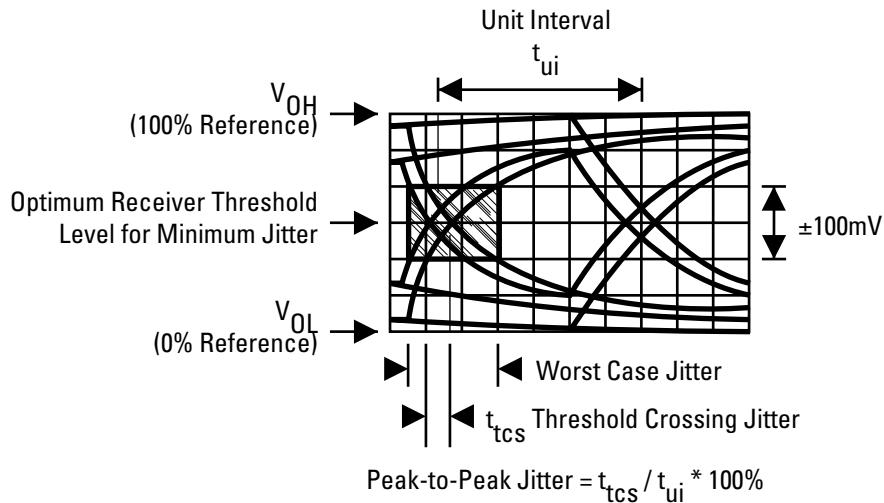
The eye pattern is used to measure the effects of inter-symbol interference on random data being transmitted through a particular medium. The prior data bits effect the transition time of the signal. This is especially true for NRZ data that does not guarantee transitions on the line. For example in NRZ coding, a transition high after a long series of lows has a slower rise time than the rise time of a periodic (010101) waveform. This is due to the low pass filter effects of the cable. The next figure illustrates the superposition of six different data patterns. Overlaid, they form the eye pattern that is the input to the cable. The right hand side of this figure illustrates the same pattern at the end of the cable. Note the rounding of the formerly sharp transitions. The width of the crossing point is now wider and the opening of the eye is also now smaller (see application note AN-808 for an extensive discussion on eye patterns).

When line drivers (generators) are supplying symmetrical signals to clock leads, the period of the clock, rather than the unit interval of the clock waveform, should be used to determine the maximum cable lengths (e.g., though the clock rate is twice the data rate, the same maximum cable length limits apply). This is due to the fact that a periodic waveform is not prone to distortion from inter-symbol distortion as is a data line.



Formation of an Eye Pattern by Superposition.

The figure below describes the measurement locations for minimum jitter. Peak-to-Peak Jitter is the width of the signal crossing the optimal receiver thresholds. For a differential receiver, that would correspond to 0V (differential). However, the receiver is specified to switch between -100mV and $+100\text{mV}$. Therefore for a worse case jitter measurement, a box should be drawn between $\pm 100\text{mV}$ and the jitter measured between the first and last crossing at $\pm 100\text{mV}$. If the vertical axis units in the figure were $100\text{mV}/\text{division}$, the worse case jitter is at $\pm 100\text{mV}$ levels.



NRZ Data Eye Pattern.

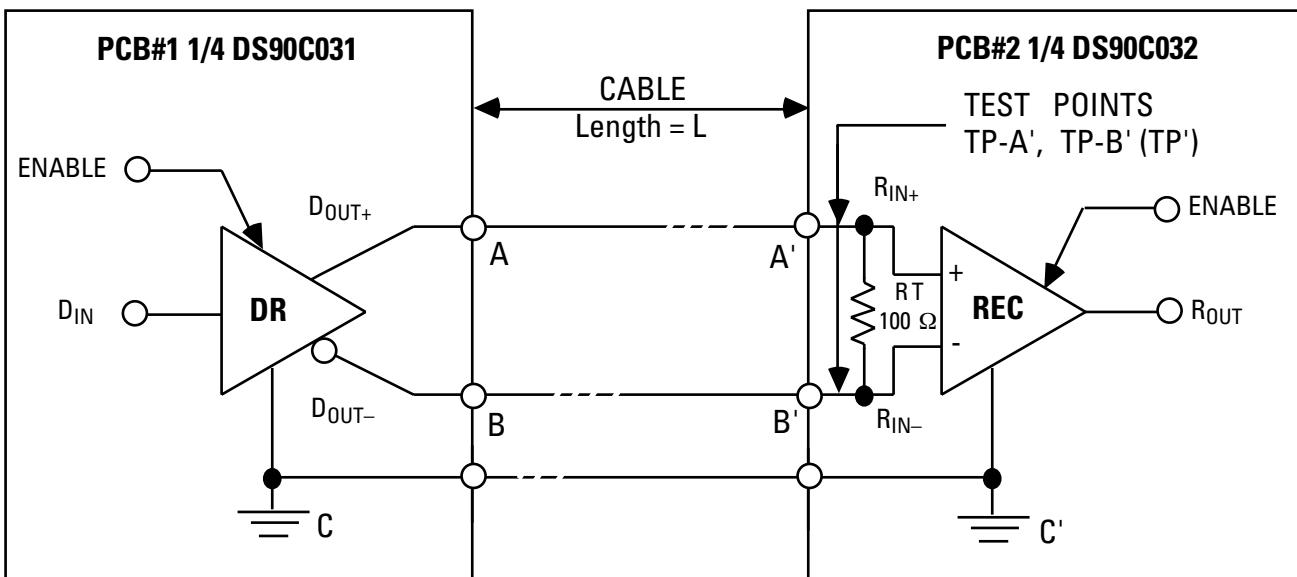
5.4.3 Eye Pattern Test Circuit

LVDS drivers and receivers are typically used in an uncomplicated point-to-point configuration as shown in the figure below. This figure details the test circuit that was used to acquire the Eye pattern measurements. It includes the following components:

PCB#1: DS90C031 LVDS Quad Driver soldered to the PCB with matched PCB traces between the device (located near the edge of the PCB) to the connector. The connector is an AMP ampite 50 series connector.

Cable: The cable used for this testing was Berk-Tek part number 271211. This is a 105Ω (Differential-mode) 28 AWG stranded twisted pair cable (25 Pair with overall shield) commonly used on SCSI applications. This cable represents a common data interface cable. For this test report, the following cable lengths were tested: 1, 2, 3, 5, and 10 meter(s). Cables longer than 10 meters were not tested, but may be employed at lower data rates.

PCB#2: DS90C032 LVDS Quad Receiver soldered to the PCB with matched PCB traces between the device (located near the edge of the PCB) to the connector. The connector is an AMP ampite 50 series connector. A 100Ω surface mount resistor was used to terminate the cable at the receiver input pins.



LVDS Signal Quality Test Circuit

5.4.4 Test Procedure

A pseudo-random (PRBS) generator was connected to the driver input, and the resulting eye pattern (measured differentially at TP') was observed on the oscilloscope. Different cable lengths (L) were tested, and the frequency of the input signal was increased until the measured jitter equaled 20% with respect to the unit interval for the particular cable length. The coding scheme used was NRZ. Jitter was measured twice at two different voltage points. Jitter was first measured at the 0V differential voltage (optimal receiver threshold point) for minimum jitter, and second at the maximum receiver threshold points ($\pm 100\text{mV}$) to obtain the worst case or maximum jitter at the receiver thresholds. Occasionally jitter is measured at the crossing point alone and although this will result in a much lower jitter point, it ignores the fact that the receivers may not switch at that very point. For this reason, this signal quality test report measured jitter at both points.

5.4.5 Results and Data Points

20% Jitter Table @ 0V Differential (Minimum Jitter)

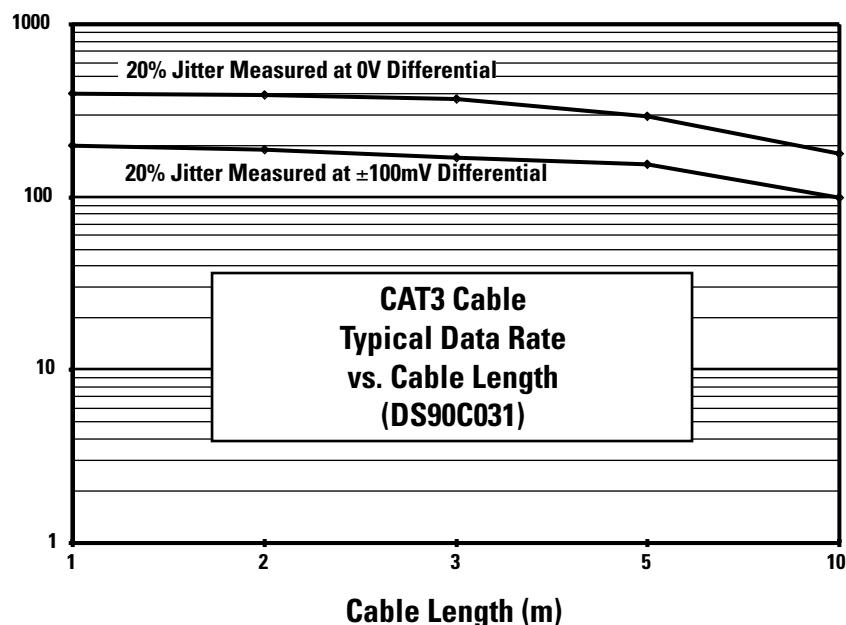
Cable Length (m)	Data Rate (Mbps)	Unit Interval (ns)	Jitter (ns)
1	400	2.500	0.490
2	391	2.555	0.520
3	370	2.703	0.524
5	295	3.390	0.680
10	180	5.550	1.160

As described above, Jitter was measured at the 0V differential point. For the case with the 1 meter cable, 490ps of jitter at 400Mbps was measured, and with the 10 meter cable, 1.160ns of jitter at 180Mbps was measured.

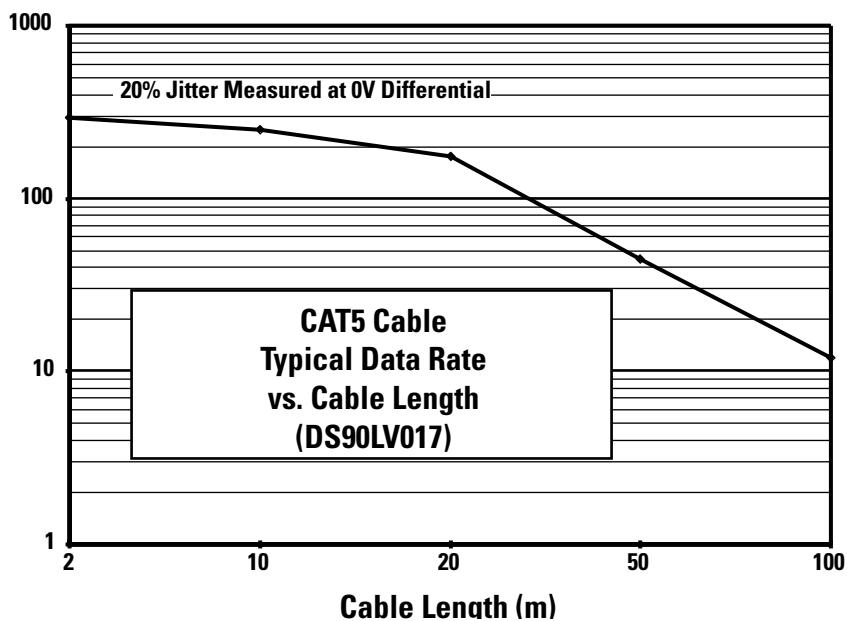
20% Jitter Table @ ± 100 mV (Maximum Jitter)

Cable Length (m)	Data Rate (Mbps)	Unit Interval (ns)	Jitter (ns)
1	200	5.000	1.000
2	190	5.263	1.053
3	170	5.882	1.176
5	155.5	6.431	1.286
10	100	10.000	2.000

The second case measured jitter between ± 100 mV levels. For the 1 meter cable, 1ns of jitter was measured at 200Mbps, and for the 10 meter cable, 2ns of jitter occurred at 100Mbps.



Typical Data Rate vs Cable Length for 0-10m CAT3 Cable



Typical Data Rate vs Cable Length for 2-100m CAT5 Cable (See AN-1088)

Care should be taken in long cable applications using LVDS. When directly coupled, LVDS provides up to $\pm 1V$ common-mode rejection. Long cable applications may require larger common-mode support. If this is the case, transformer coupling or alternate technologies (such as RS-485) should be considered.

The figures above are a graphical representation of the relationship between data rate and cable length for the application under test. Both curves assume a maximum allotment of 20% jitter with respect to the unit interval. Basically, data rates between 200-400 Mbps are possible at shorter lengths, and rates of 100-200Mbps are possible at 10 meters. Note that employing a different coding scheme, cable, wire gauge (AWG), etc. will create a different relationship between maximum data rate versus cable length. Designers are greatly encouraged to experiment on their own.

5.4.6 Additional Data on Jitter & Eye Patterns

For additional information on LVDS "Data Rate vs Cable Length" please consult the list of LVDS application notes on the LVDS web site at: www.national.com/appinfo/lvds/

At this time of this printing the following application notes were available:

<u>AN#</u>	<u>Devices Tested</u>
AN-977	DS90C031/032
AN-1088	DS90LV017/027, DS92LV010A

5.4.7 Conclusions – Eye Pattern Testing

Eye patterns provide a useful tool to analyze jitter and the resulting signal quality as it captures the effects of a random data pattern. They provide a method to determine the maximum cable length for a given data rate or vice versa. Different systems, however, can tolerate different levels of jitter. Commonly 5%, 10%, or 20% is acceptable with 20% jitter usually being an upper practical limit. More than 20% jitter tends to close down the eye opening, making error-free recovery of NRZ data more difficult. This report illustrates data rate versus distance for a common, inexpensive type of cable.

5.5.0 BIT ERROR RATE (BER) TESTING

Bit error rate testing is another approach to determine signal quality. This test method is described next.

5.5.1 LVDS Cable Driving Performance using BERT

The questions of: "How Far?" and "How Fast?" seem simple to answer at first, but after detailed study, their answers become quite complex. This is not a simple device parameter specification. But rather, a system level question, and to be answered correctly a number of other parameters besides the switching characteristics of the drivers and receivers must be known. This includes the measurement criteria for signal quality that has been selected, and the pulse coding that will be used (Non-Return to Zero (NRZ) for example — see application note AN-808 for more information about coding). Additionally, other system level components should be known too. This includes details about the cable, connector and information about the printed circuit boards (PCB). Since the purpose is to measure signal quality/performance, it should be done in a test fixture that matches the end environment precisely if possible. The actual application would be best if possible. There are numerous methods to measure signal quality, including eye pattern (jitter) measurements and Bit Error Rate tests (BER).

This report provides the results of a series of Bit Error Rate tests performed on the DS90C031/032 LVDS Quad Line driver/receiver devices. The results can be generalized to other National LVDS products. Four drivers were used to drive 1 to 5 meters of standard twisted pair cables at selected data rates. Four receivers were used to recover the data at the load end of the cable.

5.5.2 What is a BER Test?

Bit Error Rate testing is one way to measure of the performance of a communications system. The standard equation for a bit error rate measurement is:

$$\text{Bit Error Rate} = (\text{Number of Bit errors}) / (\text{Total Number of Bits})$$

Common measurement points are bit error rates of:

$\leq 1 \times 10^{-12}$ => One or less errors in 1 trillion bits sent

$\leq 1 \times 10^{-14}$ => One or less errors in 100 trillion bits sent

Note that BER testing is time intensive. The time length of the test is determined by the data rate and also the desired performance benchmark. For example, if the data rate is 50Mbps, and the benchmark is an error rate of 1×10^{-14} or better, a run time of 2,000,000 seconds is required for a serial channel. 2,000,000 seconds equates to 555.6 hours or 23.15 days!

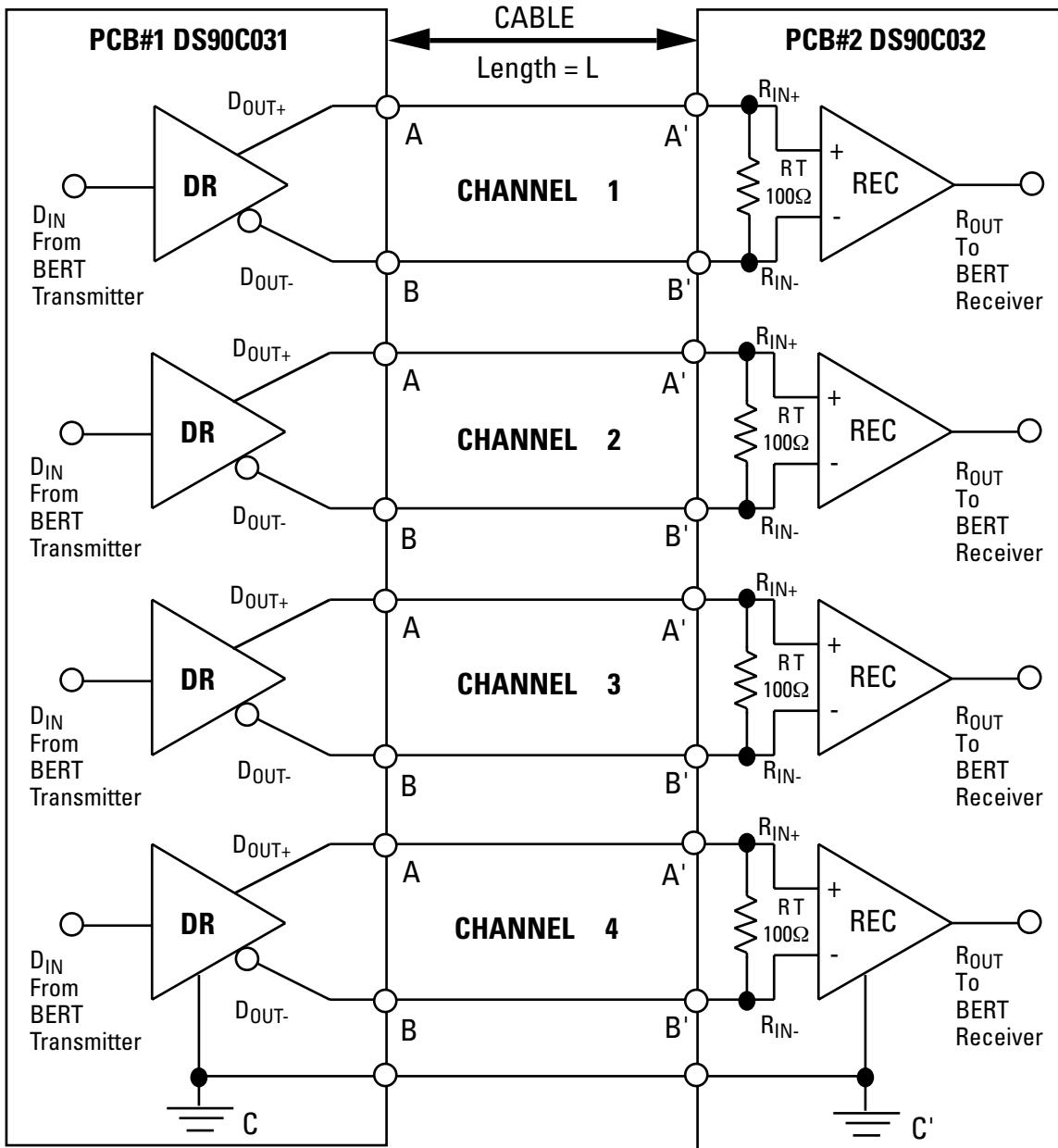
5.5.3 BER Test Circuit

LVDS drivers and receivers are typically used in an uncomplicated point-to-point configuration as shown in the next figure. This figure details the test circuit that was used. It includes the following components:

PCB#1: DS90C031 LVDS Quad Driver soldered to the PCB with matched PCB traces between the device (located near the edge of the PCB) to the connector. The connector is an AMP amplete 50 series connector.

Cable: Cable used for this testing was Berk-Tek part number 271211. This is a 105Ω (Differential-mode) 28 AWG stranded twisted pair cable (25 Pair with overall shield) commonly used in SCSI applications. This cable represents a common data interface cable. For this test report, cable lengths of 1 and 5 meters were tested.

PCB#2: DS90C032 LVDS Quad Receiver soldered to the PCB with matched PCB traces between the device (located near the edge of the PCB) to the connector. The connector is an AMP amplete 50 series connector. A 100Ω surface mount resistor was used to terminate the cable at the receiver input pins.



LVDS BER Test Circuit

5.5.4 Test Procedure

A parallel high-speed BER transmitter/receiver set (Tektronix MultiBERT-100) was employed for the tests. The transmitter was connected to the driver inputs, and the receiver outputs were connected to the BERT receiver inputs. Different cable lengths and data rates were tested. The BER tester was configured to provide a PRBS (Pseudo Random Bit Sequence) of $2^{15}-1$ (32,767 bit long sequence). In the first test, the same input signal was applied to all four of the LVDS channels under test. For the other tests, the PRBS was offset by 4-bits, thus providing a random sequence between channels. The coding scheme used was NRZ. Upon system test configuration, the test was allowed to run uninterrupted for a set amount of time. At completion of the time block, the results were recorded which included: elapsed seconds, total bits transmitted and number of bit errors recorded. For the three tests documented next, a power supply voltage of +5.0V was used and the tests were conducted at room temperature.

5.5.5 Tests and Results

The goal of the tests was to demonstrate errors rates of less than 1×10^{-12} are obtainable.

TEST #1 Conditions:

Data Rate = 50Mbps
Cable Length = 1 meter
PRBS Code = $2^{15}-1$ NRZ

For this test, the PRBS code applied to the four driver inputs was identical. This created a “simultaneous output switching” condition on the device.

TEST #1 Results:

Total Seconds: 87,085 (1 day)
Total Bits: $1,723 \times 10^{13}$
Errors = 0
Error Rate = $< 1 \times 10^{-12}$

TEST #2 Conditions:

Data Rate = 100Mbps
Cable Length = 1 meter
PRBS Code = $2^{15}-1$ NRZ

For this test, the PRBS code applied to the four driver inputs was offset by four bits. This creates a random pattern between channels.

TEST #2 Results:

Total Seconds: 10,717 (~3 hr.)
Total Bits: 4.38×10^{12}
Errors = 0
Error Rate = $< 1 \times 10^{-12}$

TEST #3 Conditions:

Data Rate = 100Mbps
Cable Length = 5 meter
PRBS Code = $2^{15}-1$ NRZ

For this test, the PRBS code applied to the four driver inputs was offset by four bits. This creates a random pattern between channels.

TEST #3 Results:

Total Seconds: 10,050 (~2.8 hr.)
Total Bits: 4×10^{12}
Errors = 0
Error Rate = $< 1 \times 10^{-12}$

5.5.6 Conclusions - BERT

All three of the tests ran error free and demonstrate extremely low bit error rates using LVDS technology. The tests concluded that error rates of $< 1 \times 10^{-12}$ can be obtained at 100Mbps operation across 5 meters of twisted pair cable. BER tests only provide a “Go — No Go” data point if zero errors are detected. It is recommended to conduct further tests to determine the point of failure (data errors). This will yield important data that indicates the amount of margin in the system. This was done in the tests conducted by increasing the cable length from 1 meter to 5 meters, and also adjusting the data rate from 50Mbps to 100Mbps. Additionally, bench checks were made while adjusting the power supply voltage from 5.0V to 4.5V and 5.5V, adjusting clock frequency, and by applying heat/cold to the device under test (DUT). No errors were detected during these checks (tests were checks only and were not conducted over time, i.e. 24 hours). BER tests conclude that the PRBS patterns were transmitted error free across the link. This was concluded by applying a pattern to the input and monitoring the receiver output signal.

NOTES

